PHYSICAL PRINCIPLES AND FUNCTION ANALYSIS OF AUTOMATIC VENTILATORS

ESSAY

Submitted in Partial Fulfilment for the requirement of
The Master Degree in Anaesthesia

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1987

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I. ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

This is to acknowledge the great help, percept and support of Dr. RAKIA SHOEIR Professor of Anaesthesiology and Intensive Care during the elaboration of this essay.

I must also express my deep gratitude to Dr. HUSSEIN SABRY Assistant Professor of Anaesthesiology and Intensive Care for his Continued guidance and advice.

They previleged me with their attention interest and reviewing of the subject of this essay.

HISTORY OF MECHANICAL VENTILATION

Early History Of Resuscitation

Andreas Wesele Vesaluis (1515 - 1564) was the first to give a detailed report about tracheostomy and the principles of modern resuscitation. Vesaluis, technique of resuscitation was the simplest form of intermittent positive pressure breathing (IPPB), a form of support which has proven to be by far the most efficient means of artificial breathing for the last 400 years.

In 1667 Robert Hook of London (1635 - 1703) repeated Vesaluis experiment by fixing a pair fireside bellows tightly into the cut trachea of a dog, keeping it alive by regular intermittent inflations.

In 1744 Jhon Fothergill of England reported a successful case of mouth to- mouth resuscitation. (Morch E.T 1985).

In 1802 E. Coleman from Ayreslin, Scotland, later veterinary professor in London recommended tracheal intubation and used silver catheter much wider than those previously employed. He suggested using a bellow for inflation and added that oxygen will be benificial. He also recommended that an electric current be passed through the heart by means of electrodes placed over the apex and base will be benificial. (Morch E. T 1985).

In 1774 Joseph Priestly and Carl Wilhelm Scheele discovered oxygen independently of each other. The french chemist Antoine Laurent Lavoisier coined the term oxygen and destroyed the phologiston theory (Priestly called oxygen depholigisticated air i.e air from which phologiston (nitrogen) has been removed).

Contraptions Applying Negative Pressure To The Surface Of The Human Body

From the middle of the nineteenth century to the first quarter of the twentieth century, an unbelievable numbers of devices were introduced which applied subambient or negative pressure to the outside of body.

Most of them offered the patient a brief prolongation of a mirable death.

Apparatus using negative pressure on the body surface can be classified in three groups, the tank respirator or "iron lung," the cuirass ventilators and the differential pressuse chamber of Saucerbruch.

a) Iron Lung:

The iron lung was a rigid container big enough to house the entire patient except for the head, which protruded through a hole with an airtight collar around the patient's neck. Intermittent negative or altarnating Positive pressure could be created by mouth.by hand or by mechanical pumps.

Physicians beleived it to be physiologically more benificial to breathe for a patient by applying negative pressure to the outside of the lungs than to blow positive pressure into the air ways. Although this belief is undoubtedly true from theoretical point of view the early machines did not prove it. They were large, cumbersome, awakward and burdened by innumerable complications. Most of all in their initial stages they did not work. (Emerson JH 1978).

The first truly workable iron lung to receive widespread clinical application was developed in 1928 at the Departement of Ventilation, Illumination and Physiology of Harvard Medical School by engineer Philip Drinker, pediatrician Charles F. Mackhann and Physiologist Louis Agassiz Shaiu.

This iron lung was comprised of a sheet metal cylinder sealed at one end. The patient's head protruded through a hole with a rubber collar in the other end. The sides of the cylinder had porthholes for observing the patient as well as numerous other small sealed outlets for manometers, blood pressure cuffs, stethoscopes etc. The pumps ran continuously, producing alternating positive and negative pressure in the tank via a system of valves.

In 1931 August Krogh constructed the first Danish respirator designed especially for clinical use. In principle it was identical to the Drinker's respirator but was improved and simplified. The motor was powered by water from the city piplines. Reciprocating movement were created by leading the water alternatinvely to the upper and lower compartements of a piston cylinder which acted on a large spirometer bell.

The most important improvement of iron lung was made in 1932 by J.H. Emerson. He added a transparent airtight dome that could be fitted over the patient's head .It provided intermittent positive pressure at the head and mouth so that the tank could be opened, enabling good and unhurried nursing care to the patient's immobile body. (Emerson J.H 1978).

Complications of Iron Lungs:

(1) Good nursing care was nearly impossible in the first iron lungs. Simple procedures eg. taking the temperature or blood pressure and giving a bed bath were nearly impossible befor Emerson developed his transparent dome.

(2) Many patients developed cloustrophobia, disorientation, and lonliness from being encapsulated in a closed tank.

(3) Patients's necks were always sore from the

necessarily tight collars. It was so constricting that the patient could constantly hear their own pulses.

b) Cuirass Ventilators:-

Cuirass ventilators were also rigid, intermittent negative pressure containers, however they covered only the patient's chest or chest and abdomen, leaving the extremities and pelvis accessible. Two additional advantantages over the iron lung were their economy and portability.

According to Wollan the first cuirasses were made by Ignez Vonhauk of Austria in 1874, by Alexander Graham Bell in 1882 and by Rudolph Eisen Pmenger of Piski in 1901. In a comparison between cuirasses and tank respirators, they found that if they took the tidal volume produced by the tank as 100 percent, the thoracoabdominal cuirass produced 61-63 percent but the thoracic cuirass only 47 percent . Also the cuirass required much more negative pressure to produce the same tidal volume as the tank.

In 1953 Toker and later Green and Coleman, described a completly new use for the curirass when he used a kifa cuirass to ventilate patients during general anaesthesia for bronchoscopy and laryngoscopy, a procedure which previously had represented a very difficult problem for anaesthetist.

c) Saucerbruch's Differential Pressure Chamber:-

In 1904 Ernst Ferdinand Saucerbruch transformed a small operating room into a sort of enlarged pleural space. He constructed a small airtight operating room where the patient's body and the surgeon were inside. and the patient's head outside. The hole around the patient's neck is airtight. By continuous suctioning Saucerbruch created a subatmospheric pressure inside the operating room equal to the pleural pressure and the patient's head and upper airways were exposed to atmospheric pressure. In this way he expanded the lungs during open thoracotomy and theorised that the patient could breathe spontaneously while receiveing inhalation anaesthesia.

Saucerbruch's "pneumatic chamber' as this contraption was called, solved a theoretical problem from the physiological point of view. However, even the most technccally perfect chamber broke down during clinical use for several reasons:

(1) The surgeon and his assistants had very little room for movement,.

(2) The heat was almost unbearable. and it was extremely difficult to communicate satisfactorily with the

anaesthiologist outside the chamber. For this reasons and others the differential pressure chamber method was abandoned and today is nothing more than a historical curio. (Morch E.T. 1985).

Back To The Direct APPROACH:

During the last decade of the nineteenth century ,knowledge of respiration and the support thereof was more than adequate for the purpose of open chest surgery. It included understanding basic physiological principles. tracheal intubation with cuffed tubes. oxygen compressed in tanks. ventilators. devices for producing continuous positive pressure or intermittent positive pressure with retard of expiration and apparatus for general anaesthesia. In 1899 Rudolf Matas of New Orleans wrote The procedure that promises the most benefit is: rythmic maintenance of artificial respiration by a tube in the glottis" (Matas R; 1899).

On the European continent the simple direct approach combining artificial respiration with tracheal intubation was presented by Kranz Kuhn in Kassel Germany in 1905. He was the first to pass a suction catheter through endotracheal tube. In 1910 Lawen and Sievers in Friederich Trendelburg,s departement in Leipzig, reported a piston ventilator which applied positive and negative pressure with supplemental oxygen through an endotracheal tube.

From 1910 to 1930 significant advances occured in experimental surgical and physiological laboratories. Negative and positive - pressure cabinets never became popular among american surgeons. Instead they developed a variety of intralaryngeal tubes for direct introduction of air into the lungs from pumps devised for this purpose . In 1910 for example, the Philadelphia surgeon George Morris Porrance and the New York surgeon C.A Elsberg, as well as Lawen and Sievers from Trendelburg's departement in Leipzig all published outstanding work on these procedures.

In 1913 Henry h. Janeway of New York described an ingenious machine for anaesthesia and artificial respiration with a cuffed endotracheal tube exactly the shape of the ones used today. He also developed the first modern laryngoscope. Janeway also appreciated the potentially adverse effect of positive pressure on circulation. (Janeway H.H. 1913).

MODERN VENTILATORS

Modern ventilators can be traced back to Scandinavian initiatives taken in 1915 by Holger Molgaard of Copenhagen. T. Thunberg of Lund. and especially by K.H. Giertz of Stockholm in 1916.

Giertz. showed experimentally that artificial ventilation obtained through positive pressure rythmic insuflation was superior to every form of constant differential pressure breathing. He enlisted the help of the skilled nose, ear and throat surgeon Paul Frenckner to evolve a series of endotracheal tubes. He also convinced the experimental engineer Emil Anderson of the AGA Company to develop an air driven ventilator the "spiropulsator". It's essential valve was the AGA flasher for automatic sea buoys designed to send out precisely timed flashes of burning acetylene. The first commercial model of the Spiropulsator was offered in 1940. Clarence Crafoord used the Spiropulsator while working on the technical prolems of pneiumanectomy (Crafoord 1938).

- At the beginning of world war II : In 1940 Ernst Trier Morch designed his first piston ventilator. This, the first clinicaly proven volume ventilator was used in a great numbers of thoracic operation between 1940 and 1949 in Denmark.

In 1944 K.B. Pinson of Manchesster devised an automatic ventilator (pulmonary pump). The apparatus consisted essentially of two piston pumps. One took over respiration and the other employed suction to evacuate secretions or pus from the trachea or bronchial tree.

- During the second world war, a motor cycle engineer, J.H. Blease of London, Produced an anaesthetic apparatus. Blease's efforts were followed by dsigns of

Esplen's "Aintree" ventilator in 1952 and the Fazakerley ventilator in 1956.

- Most of the essential priniciples of positive-pressure mechanical ventilation and airway care were implemented during 1952 Danish poliomylites epidemic. Chest physiotherapy with meticulous attention to postural drainage, mannual assistance to coughing and tracheobronchial aspiration of secretions were now universly applied. Inspired gas with partial rebreathing was humidified, albient incompletly in the to and fro system. Oxygen toxicity was avoided by using mixtures of nitrogen and oxygen. Large bore, cuffed tracheostomy tubes were used to facilitate controlled ventilation and air way protection. Adequacy of oxygenation was judged by clincal observation, measuring arterial oxygen saturation or oximetry. Intermittent pulmonary hyperinflation, a forerunner of the sighing described in 1959 by Mead and Collier were emprically applied to overcome the complaint of dyspnea commonly expressed by patient with ventilatory failure despite what seemed to be adequate oxygenation and ventilation. As the patient's ability to breath spontaneously improved weaning was accomplished by gradual reduction in the number of assisted breaths, the foreruner of present day Intermittant mandatory ventilation (IMV).

- Similar expericnces were reported in the United States during a minor poliomyelitis epidemic in kansas